

## END-TO-END MODELING OF SARDINE AND ANCHOVY IN THE CALIFORNIA CURRENT SYSTEM

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End-to-end models are receiving increasing attention as a quantitative tool for investigating marine ecosystem responses to climate variation and fisheries management. End-to-end models typically combine submodels of physics (hydrodynamics), lower trophic levels (nutrient-phytoplankton-zooplankton, NPZ), and upper trophic levels (fish, birds, fishers) into a single modeling framework (Plagányi 2007). Such models are attractive because they can simulate a wide variety of effects, including ecosystem responses to interannual environmental variation, changes in fishing, and episodic and long-term trends in climate conditions. Our focus in this paper is on the development of an end-to-end model (climate to fish to fishers), using the sardine-anchovy system of the California Current (CC). The sardine-anchovy low-frequency population cycles have been studied for decades (Lluch-Belda et al. 1989). We focus here on how interannual variation in environmental conditions affected the decadal cycles in sardine and anchovy populations.

Our end-to-end model is 3-dimensional, time-varying, and multispecies, and consists of four coupled submodels: hydrodynamics, Eulerian nitrogen-phyto-

plankton-zooplankton (NEMURO NP<sub>2</sub>Z<sub>3</sub>), an individual-based full life cycle anchovy and sardine submodel, and an agent-based fishing fleet submodel (Rose et al. 2015). All submodels were coded within the ROMS community software package, and used the same resolution spatial grid and were all solved simultaneously to allow for possible feedbacks among the submodels. A historical simulation of 1959–2008 was performed (fig. 1) that showed a switch from anchovy dominance to sardine dominance in the mid-1990s. A more in-depth analysis of the causes for the population cycles in the historical simulation is reported in Fiechter et al. (2015). Results illustrate how slightly different temperature and diet preferences between sardine and anchovy can lead to their different responses to environmental variability. Simulated adult population fluctuations were associated with age-1 growth (via age-2 egg production) and prey availability for anchovy, while they depended primarily on age-0 survival and temperature for sardine.

Our analysis demonstrates that the technology is available for developing and using 3-dimensional fully-coupled multispecies end-to-end models. We conclude with a discussion about the prospects for using such end-

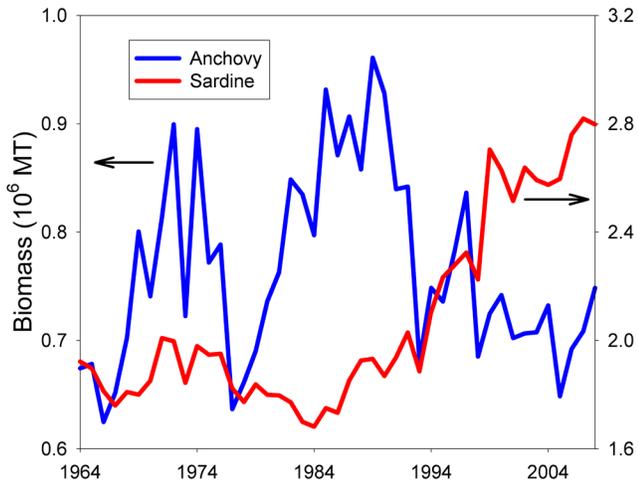


Figure 1. Annual values on January 1 of age-1 and older simulated biomasses of anchovy and sardine in the historical simulation.

to-end models for strategic and tactical predictions. The time is now for development and testing of these end-to-end models so we are ready with models of sufficient and documented confidence for wide-spread usage within the next decade.

## LITERATURE CITED

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